



Two types of glitches in a solid quark star model[†]

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Abstract The glitch of anomalous X-ray pulsars & soft gamma repeaters (AXP/SGRs) usually accompanied with detectable energy releases manifesting as X-ray bursts or outbursts, while the glitch of some pulsars like Vela release negligible energy. We find that these two types of glitches can naturally correspond to two types of starquake of solid strange stars. By applying the EoS of quark cluster star and some realistic pulsar parameters, we can reproduce consistent results compared with previous constraints and observations.

Key words dense matter-stars: magnetar-stars: neutron-pulsars: general

A glitch is a sudden increase in pulsars spin frequency, ν , and the observed fractions $\Delta\nu/\nu$ range between 10^{-10} and 10^{-5} (Yu et al. 2013). In neutron star models, pulsars are thought to be a fluid star with a thin solid shell. The physical mechanism of glitch is believed to be the coupling and decoupling between outer crust (rotating slower) and the inner superfluid (rotating faster) (Anderson & Itoh 1975; Alpar et al. 1988). However, the absence of evident energy release during even the largest glitches ($\Delta\nu/\nu \sim 10^{-6}$) of Vela pulsar is a great challenge to this glitch scenario (Gürkan et al. 2000; Helfand et al. 2001). At the early years of glitch study, authors believed that glitch mainly happens on young pulsars, but the glitches detected from AXP/SGRs (anomalous X-ray pulsars/soft gamma repeaters), usually accompanied with energy release (Kaspi et al. 2003; Tong & Xu 2011; Dib & Kaspi 2014). Thus, the glitch can be divided into two types depending on the energy releasing. We find that these two types of glitches can naturally correspond to two types of starquakes of solid stars. The two types of starquakes can be divided into bulk variable starquake and bulk invariable starquake based on the volume variation.

The bulk variable starquake was induced by the accretion. During the accretion, the mass of the star increases, and the density-radius relation varies. If the star is solid, this

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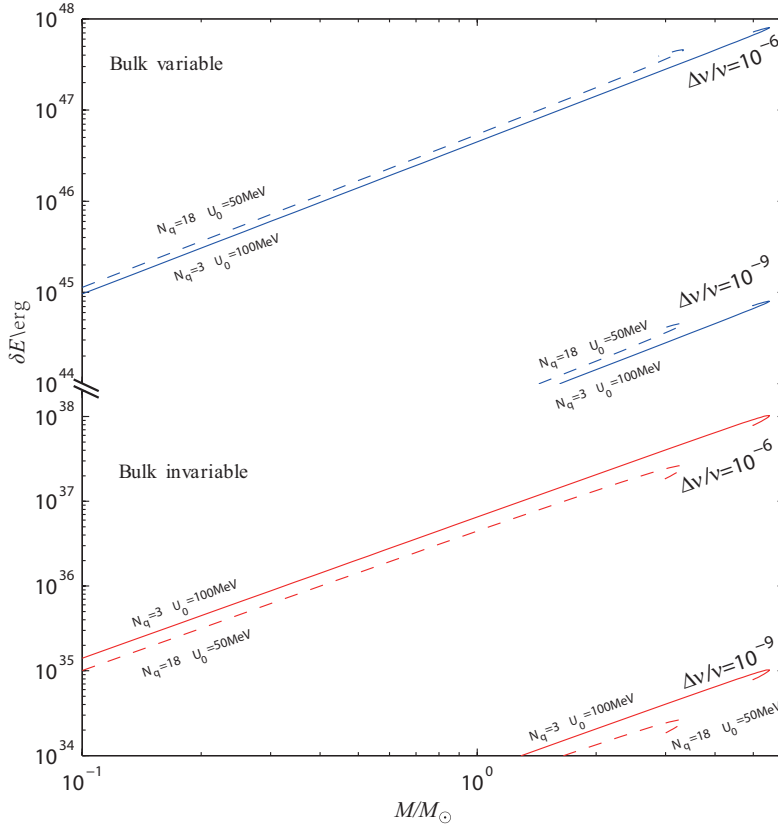


Fig. 1 The total energy release during the bulk-variable glitches and bulk-invariable glitches with amplitudes of 10^{-6} and 10^{-9} . The Lennard-Jones interaction is applied as an approximation to work out the mass-radius relation (Lai & Xu 2009). There are two main factors in this approximation: the number of quarks in one cluster (N_q) and the depth of the potential (U_0). The case of 3-quark clusters with potential of 100MeV (solid lines) and 18-quark clusters with potential of 50MeV (dashed lines) are considered. It's also worth noting that the energy release during a bulk-invariable glitch is related to the time intervals between two glitches. In this calculation the glitch is thought to happen once per month and the spin down power is calculated according to the observational data of Vela.

density-radius relation variation means structure transformation. But the elasticity of solid body would resist this transformation. As the accreting carrying on, the elasticity becomes

larger, until it gets to its upper limit. Then the star will collapse. It leads to a smaller radius and a smaller inertia moment, then the spin frequency will become larger. With a typical pulsar and glitch parameter, the estimated energy releasing coincides to the actually observed value of AXP or SGR glitch. It means that this theory is rational to explain the glitch of AXP/SGRs.

The other type starquake occurs without a bulk variation, and it is induced by the spin-down of the pulsar. With a strong magnetic field, the pulsar emits dipole radiation and losses rotating energy as it spins, and it would spin-down. If the star is composed with uniform liquid, its shape will be Maclaurin ellipsoid, and the ellipticity will decrease as the star spin-down. For a solid star, the shearing force will resist this ellipticity variation. As the pulsar spin-down, this shearing force becomes larger. And the star would crush when the shearing force reaching a critical value. The inertia moment becomes smaller and the rotation speed up. With some available parameters, the glitch amplitude can be up to 10^{-6} even if the epoch between two glitches is about 1 year.

Fig. 1 show our calculating result of the two types of starquakes. Note that **there is a break in the vertical scale of about 8 orders of magnitude**. Actually, for same glitch amplitude, the releasing energy of bulk variable will be about 10^{10} times of bulk invariable starquake energy releasing. Now, we can build the correspondence between the two types of glitches and starquakes based on the energy release.

In neutron star models, a pulsar is thought to be a fluid star with a thin solid shell. In fact, so far only quark star and quark cluster star model develop a solid star model. Then the two types of glitches may be an implication that the pulsar is composed by quark matter or quark cluster matter.

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